Computer system for processing the ENT examinations

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***Abstract*—** This paper deals with the design and preparation of the computer system for performing audiometric examinations and their evaluation. System focused on elimination of the redundant and repetitive tasks in the certain types of hearing function examinations, with the main attention on audiometric examination. Proposed system aim to reduce time needed to examine patient and also provides the full digitization of the results. One of the objectives is also the task to avoid the redundancies in routine steps, such as patient personal data insertion and search and measured results sharing. Proposed system connects all particular parts into one unit, sharing one database and cooperates via computer network. System eliminates paper form record and replaces them with a digital database records. The obtained database can lately become the base for subsequent processing, for example in expert systems or artificial intelligence using the methods of data mining. This system has capability to increase diagnostic potentials. In cooperation with physicians, the above mentioned system has been designed, developed and tested under real conditions.

***Keywords*—** Audiometry, examination, hearing lost, Fowler, ENT.

I. Introduction

THE large group of the medical examinations with explicit steps still have no computer support even the algorithms to perform them have fixed structure. Sometime the computer support exists, however it is not centralized in one system [7]. This contribution deals with disadvantages of current situation in Czech ENT offices, but situation is similar or even worse in many other countries. Offices are equipped with old devices and software. The exchange, for reasons of cost investment, is slow and partial. This is perhaps a logical evolution, but often builds inconsistent systems. For example, modern audiometer has good computer modules, but often lacks the possibility of cooperation with ambulatory software. Such modules have no link to physician medical records. Especially older or regional systems are not supported at all.

This evolution leads to global systems that are obviously preferable because it ensures greater uniformity of physicians, but the transition to them is costly and in real life doctors rather prefer to work in their old systems and put off upgrading their offices. Another example of weaknesses of many systems, is the evaluation of measurement results according to a given criteria. There are still a lot of offices, where calculation of hearing loss based on Fowler method (CPT) [4] is often carried out using, a hand calculator, printed table and pencil. Or even common calculation of average value, for example, evaluated according to WHO [6]. Undoubtedly a trivial task, but at this time it would certainly not be the act done by a doctor or nurse. It should be an automatic output of the software that performed measurements. There is no problem to build and offer software to perform simple math actions, most of these task could be easily performed by table processor such Microsoft Excel, even some computer proficient doctors operate in this manner, but this is not the correct direction of development. The main disadvantage is data access. If there is a computer software to measure data but these data must be subsequently copied or hand written into other autonomous application, something is faulty. There are many other examples, let's consider common situation where physician treaded patient and healing takes several months, it is extremely suitable to compare results from particular visits to see improvement. Current routine however does not provide many sufficient ways, meaning fast, subjective methods. This works is trying to change it.

Presented work as indicated earlier also aims to way, improving the current situation, where doctors are forced to constantly rewrite results into the various forms, software tools; perform additional calculation and so on. However, this work is not focused to replacing specialized software tools but complement them and rather to provide the ability to easily export and import measured date into them, without rewriting which is the most significant disadvantage of current situation. All said above is considerably lengthen the time needed to perform the necessary tests, and thus it is increasing the time patients need to spend in the physician office and everything is logically reflected in the final price of such examination. However, if time needed to process examination will be reduced, it at least makes doctors work easier, or enable to treat more patients. From the market perspective, presented system reduces the cost of the examination.

Even the system is still in developing process; it bases were given about seven years ago and for several years is already tested in physician offices. Such tests are not just helping to improve the system and tune the errors but provides powerful instrument to collect digital data.

At every stage of the solution of this system, the close cooperation with doctors and paramedical staff is required and applied.

II. Basic Objectives and Ideas

The work is focused on variety of examination; however the pure tone audiometry is one of the frequently performed and significant for selected targets [3].

Pure tone audiometry is the key hearing test used to identify hearing threshold levels of an individual, enabling determination of the degree, type and configuration of a hearing loss. Thus, provides the basis for diagnosis and management. Pure tone audiometry is a subjective, behavioral measurement of hearing threshold, as it relies on patient response to pure tone stimuli. Therefore, pure tone audiometry is used on adults and children old enough to cooperate with the test procedure [1][5].

A. Improvements

The aim for the improvement of this examination was to remove all the rewriting and hand calculations. It contained the following tasks:

- Implementation of the connection to the PC provides possibility to obtain online access to measured data [2].
- Preparation of printing and exports into graphic file formats.
- Proposal of algorithms, development and subsequent implementation of the calculation of hearing loss according to Fowler, the mean rate of loss of speech, etc.,
- Implementation of communication between computers within a local network - usually a physician and nurse are working on different computers and it is appropriate to share information.
- Implementation of interconnection with the most commonly used specialized programs (third-party products) and by obtaining data directly from the already existing databases, as well as the possibility of copying the final results to patient medical records.

The following figure shows the area covered by the proposed system.

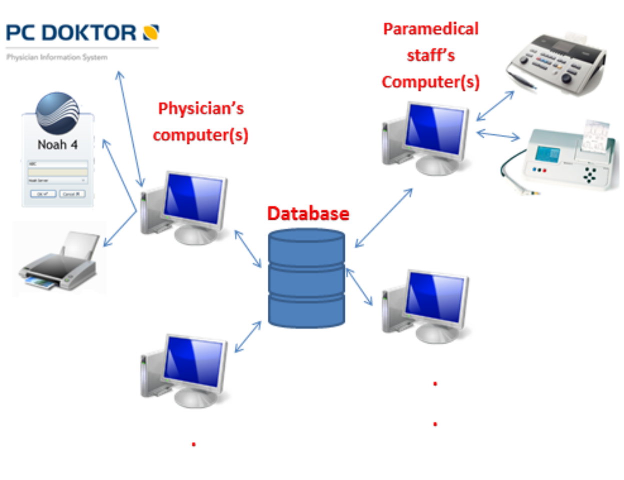

Fig. 1 Working area of the proposed system

III. Subjective ENT Examinations

Beside tone audiometry, there are several subjective examinations. It is a set of basic hearing tests; the successful implementation depends on cooperation examined person. Despite that, compared with objective methods are affected by a number of errors, their role in diagnosis is indispensable.

A. Classic audiometry hearing test

The test has two inseparable parts, and when it is determined both hearing and understanding words is investigated. The hearing ability is examined by regular loud talk and whisper. Distance, from which the words are pronounced, is gradually increased until the maximal set or distance where patient is not able to hear understands and correctly repeated. Determined distance is used as a criterion for assessing the degree of hearing loss, a pointer to possible type of hearing disorders and guide to the audiometric curve on air conduction.

The results are evaluated in three factors:

- distance (determined by degree of hearing loss) - for normal hearing is considered to understand a whisper voice from a distance of 6 meters,
- understanding the difference between a whisper and loud speech (possibility of sensorineural cochlear defect),
- difference in the understanding of high-frequency and low-frequency sounds (shows the character of the audiometric curve of air conduction).

Marks:
Loud speech *V (vox)*
Whispers *Vs (sibilant vox)*

The examination of the patient with normal hearing has this entry:

6 m - *V* - 6 m, 6 m - *Vs* - 6m,

the numbers describe the distances in meters for left and right ear.

Hearing impairment on the right would thus be written as follows:

4 m - *V* - 6 m, 2 m - *Vs* - 6m.

Implemented improvements

Due to the method of examination is sufficient to store measured values into the patient record in database and enable their export into physician information systems.

The doctor will write the examination results into the form in proposed system (in the case of limited sets – the values can be selected from preset list). Improvements in these examinations are to speed up the results recording and store them in digital form. Diagram is shown at figure 2. In the practical implementation, the examination was realized in the same form as the examination of tuning-forks test.

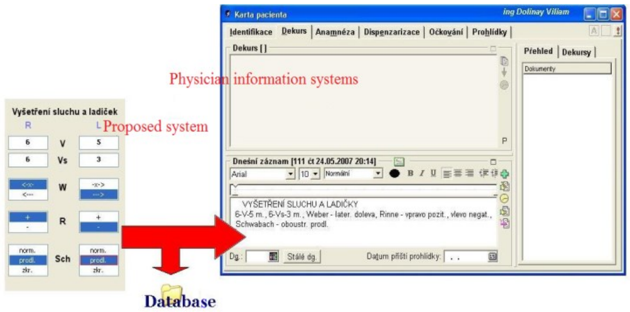

Fig. 2 Diagram of processing the results of hearing tests and tuning-forks

B. *Tuning-forks test*

The tuning-forks test is performed in three basic methods.

Weber

- compares bone conduction both ears. Sound perception in deaf ears remains symmetrically located somewhere in the middle. If one ear has worse hearing, there is a unilateral acoustic perception.

Rinne

- compares the level of air and bone conduction of the same ear. Better subjective perception of air conduction - Rinne positive - with sensorineural hearing defect. Increased perception mediated by bone conduction - Rinne negative - the type of conduction disturbances.

Schvabach

- compares the patient's bone conduction with investigating person conduction (the smallest practical importance, obsolete)

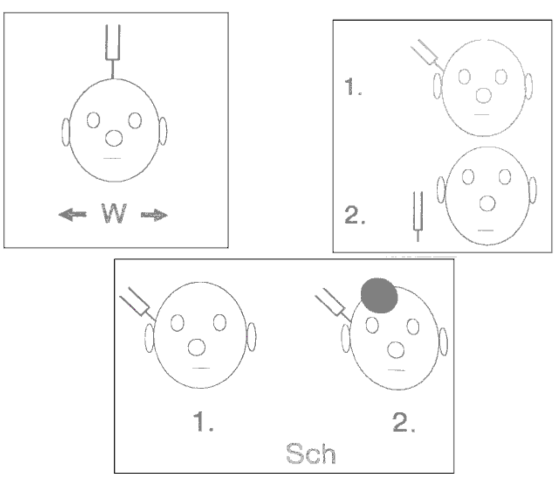

Fig. 3 Weber, Rinne and Schvabach test [4]

Implemented improvements

The examination is carried out in practice together with the hearing test examination. Both have mostly simple input to a form by selecting a predefined value, quick export to outpatient programs and archiving in the database were also implemented.

IV. Tone Audiometry

The tone audiometry is the most basic and most frequently performed examination. From the curves course can be determine the type of hearing impairment, determined the harm of hearing, etc. Audiometry examination procedure is shown on fig. 4. The patient sits in a soundproof chamber and listens for tone pulses in headphones. When signal is captured, patient states to doctor by button.

Fig. 4 Audiometry examination procedure [8]

However, there are also a number of regulations that require accurate representation of hearing by numbers or symbols. These include the assessment of vehicle driving capabilities, suitability for inclusion in employment and more. In addition, there must also be a possibility of mutual comparison of results between different departments or individual patients over time. The most important criteria for assessing the degree of hearing loss from audiogram include:

- assessment of the curves,
- assessment of the average speech or ISO frequencies,
- calculating percentages according to Fowler.

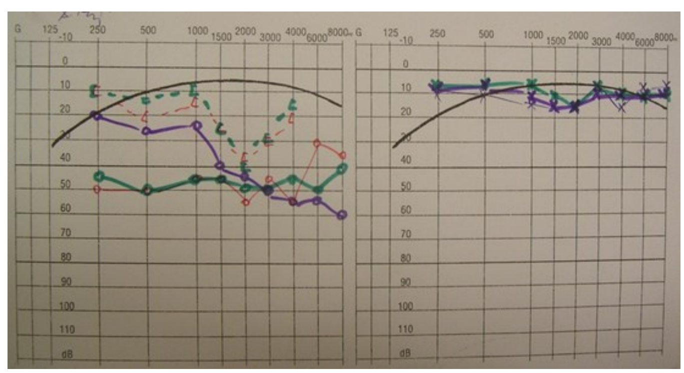

Fig. 5 Traditional way of writing curves on paper

Percentage by Fowler is considered a versatile parameter quantifying hearing status based on audiometry examination.
Expanded criteria based on the value Fowler is for example the diagram for the evaluation of occupational hearing disorders. For more detailed description see [4].

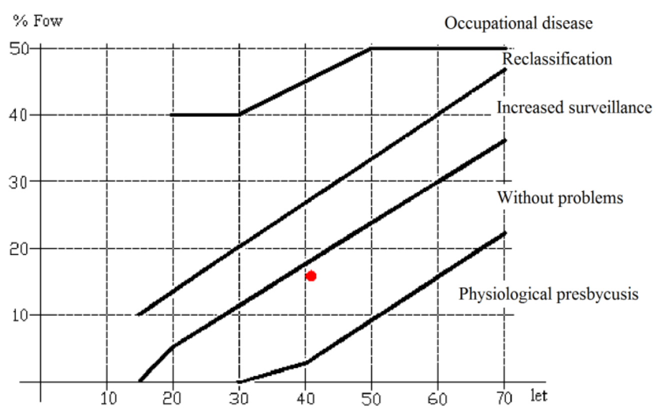

Fig. 6 Diagram of inclusion in the group of hearing loss

Percentages according to Fowler

The calculation is done using a special table where each hearing loss in dB assigned percentage. It is expressed as a percentage corresponding to the importance of communication frequencies. The criterion is based on air conduction hearing loss at frequencies of 500, 1000, 2000, and 4000 Hz. Percentage valuesin one ear are added together. Calculation of total losses need mutual subtracting the values measured for each ear, the difference is divided by four and the value obtained is added to the better hearing ear.

$$F = \frac{B - A}{4} + A \quad (1)$$

where A is % loss of better hearing ear,
B is % loss worse hearing ear,
F is % total hearing loss according to Fowler.

V. Other Examination

A. *SISI test*

Performs at the level of intensity 20 db above the individual hearing threshold using a special tone. It is a continuous tone every 5 seconds is automatically increased by 1 dB at time 200 ms. Measurements are taken in batches of 20 counts and counts how many pulses immediate increase in the intensity of the examinee recorded. Each precise identification of one pulse is expressed by the value of 5%. For cochlear hearing defect is an important gain 80-100% for retro-defect gain 0-20%. Other values are not characteristic.

Marks:
positive … 80 - 100 %
uncertain … 25 – 75 %
negative … 0 – 20 %.

Implemented improvements

For this test, as well as all previous, it was important to prepare the measurement, visualization and storage of measured values. The examination SISI test is uniquely defined and rating algorithm and it is possible to integrate it into the system. Algorithm evaluation of this test is shown in the following diagram.

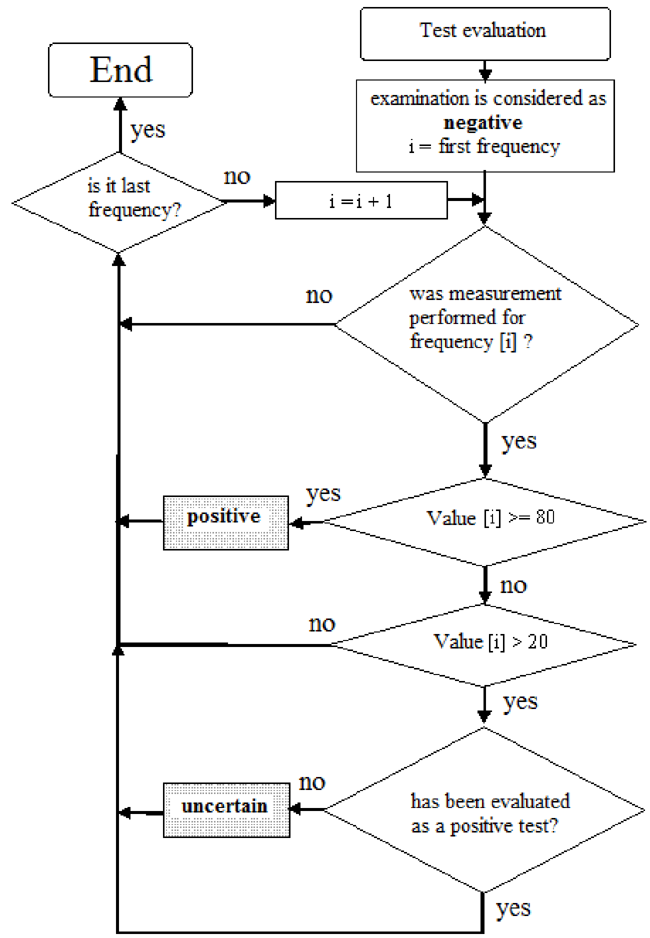

Fig. 7 SISI test evaluation algorithm for one ear

Each ear is evaluated independently. If any of the values reaches the 80% of the entire examination is evaluated as positive. To classify results as negative, all values on measured frequencies have to had a value less than or equal to 20%. All remaining cases are classified as uncertain test result [4]. The algorithm is implemented in proposed system as one of its modules.

B. *Tympanometry*

Tympanometry tests are completely objective examination to assess the patient's auditory apparatus. Cooperation of the patient is minimal. Suffice it to sit still and limited facial expressions. Testing can be performed on small children if they manage to entertain and calm.

The principle of the diagnostic method is based on the inserting of the probe into the external auditory canal, which is thus hermetically sealed. Changing pressure is evaluating the eardrum membrane and ipsilateral and contralateral stapedius reflexes to evaluate the stiffness of the chain of middle ear ossicles. The results are presented in tympanometric curves.

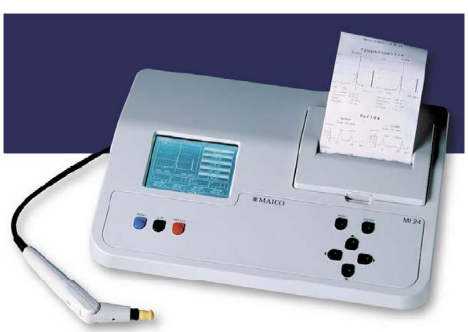

Fig. 8 Tympanometer device Maico MI24 [9]

Implemented improvements

As already mentioned, the results of this examination are tympanometry curves.

The fig. 8 shows one of the commonly used tympanometers and there can be also seen form in which the curves reach a doctor - it is the printed output.

Even though modern tympanometry allow connection to a personal computer, this option is not used very often. Programs supplied to the devices do not work with the physician information systems and therefore patients' data must be duplicated, portability to export daily report to physician information systems is reduced to usage of Windows clipboard. Software is usually supplied equipment must be additionally purchased and price, according to a doctor's opinion does not correspond to the limited benefits it brings.

If regular tymanometry test is done, the physician obtains a graphic representation of the measured values in the form of curves called tympanogram and reflexes. Curves are always independent for the left and right ear. Middle ear muscle reflexes can be scanned at the ipsilateral or contralateral stimulation of different tonal stimuli. Most often, the response observed at 500, 1000, 2000 and 4 000 Hz.

Fig 9 shows output from proposed system.

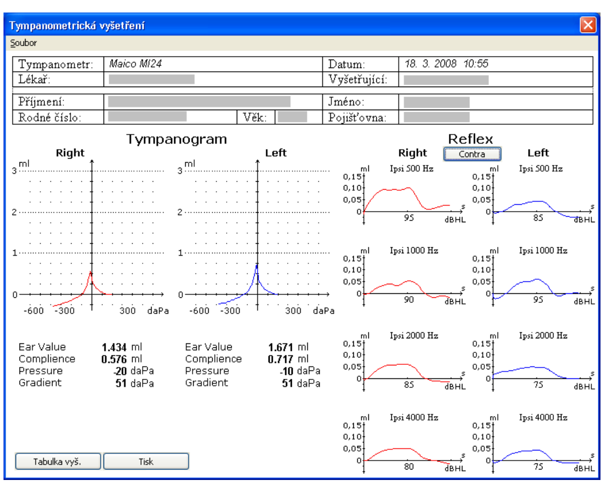

Fig. 9 Tympanometry examination curves

Implemented improvements for tympanometry examinations consist in the possibility of a direct connection tympanometer device with software tools of proposed system. Tympanometry module, as well as other implemented modules allows importing patient data from physician information system and on the other hand, exporting exam report into the same program. In addition to these standard enhancements for tympanometry examination was implemented automatic classification of curves.

Depending on the nature of the curve, following norms are specified:

Tympanogram: A, B, C

Type A: Peak in tympanogram between + or - 100 daPa.

Type B: No identifiable peak. Equivalent ear canal volume within normal limits (B low) or equivalent ear canal volume exceeds normal (B high)

Type C: Peak in the tympanogram at greater than -100 daPa. This can be shallow or deep as well

Reflexes: identifiable, no-identifiable (denoted by the symbols +, -)

Information required for results classification are calculated directly by typanometer device or by modules of the proposed system. Implemented were these calculations:

Tympanogram

Implemented algorithm determines the location of the tympanometric curve peak and its type. Data describing this curve are from the tympanometer obtained in the form of tables dependence on volume changes in pressure. The peak of the curve is considered as the maximum value achieved by a change in air volume. Type curve is then derived from this value and the pressure at which the peak was reached.

Algorithm can be minimized into simple diagram, see fig 10.

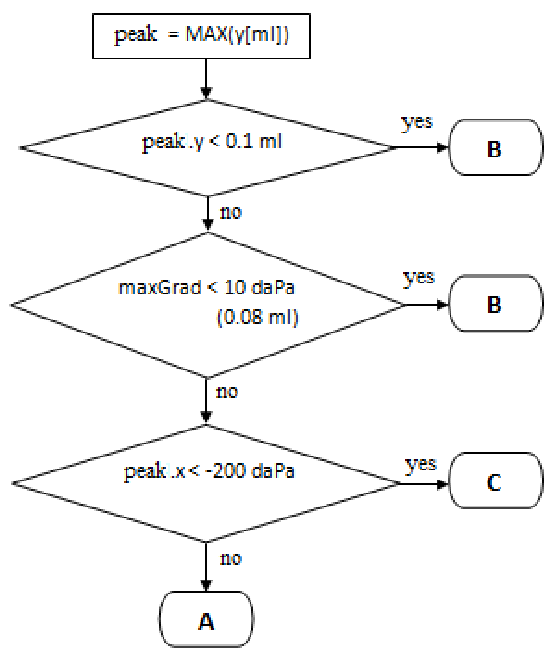

Fig. 10 Determination of the curve type

Reflex
To determine the reflexes the value of identifiable reflex contraction is required. Tympanometr automatically searches for the lowest sound pressure that still causes identifiable reflex. In the case of ipsilateral and contralateral reflexes the volume change is monitored for one second. As well as tympanogram, the reflex curves are available in tabular form, depending on the time. Numerical representation of the contraction value is not usually included in the tympanometer output data. Tympanometry module of the proposed system uses the following calculation to add this value.

$$Stah \approx h * \sum_{i=1}^{n-1} \frac{y_i + y_{i+1}}{2} \qquad [ml/s] \qquad (2)$$

where: h is the scanning period
y volume [ml].

VI. Working with Data

As mentioned in the previous chapter, proposed system implements steps improving various parts of audiometric examinations.

A. Data sharing

First step is the patient personal data sharing. Unfortunately ENT specialists use a number of different software that is specialized for a particular task. This software usually comes from different producers and there is no interconnection. In this situation proposes system can function as crossroads. This system implements functions to automatically import patient from a number of local used software and therefore ENT do not perform manual copying of the data from the medical record software.

An important part of data sharing is its exchange with paramedical staff performing some examinations. Such as tone audiometric test, tympanometry, etc. This task was also implemented. ENT can electronically send patient for such examination and he (she) is automatically notified when it's done.

For the above mentioned examination were prepared hardware communication modules to online connect a particular device and visualize obtained data. Proposed system is not commercial product of specific equipment manufacturer; therefore it tries to cover a wide range of devices. Of course, the device must be provided with appropriate documentation and permission to incorporate it into the third party software. There is prepared communication with audiometers of these producers (select devices only):

- Maico
- Interacoustics
- Siemens
- Amdpaid
- Madsen
- Videomed

The final aim of the proposed system is sharing the results. As mentioned in chapter 2.1, measurement data is often necessary to print, transfer to patient medical records, or share with other systems for specific processing. One example can be the widely used software HIMSA NOAH, into which can be transferred patient personal information and audiometric measurement results. For such third-party software is export realized through hotkeys macros.
Window of the NOAH 4 automatically filled by proposed system is shown on fig. 11.

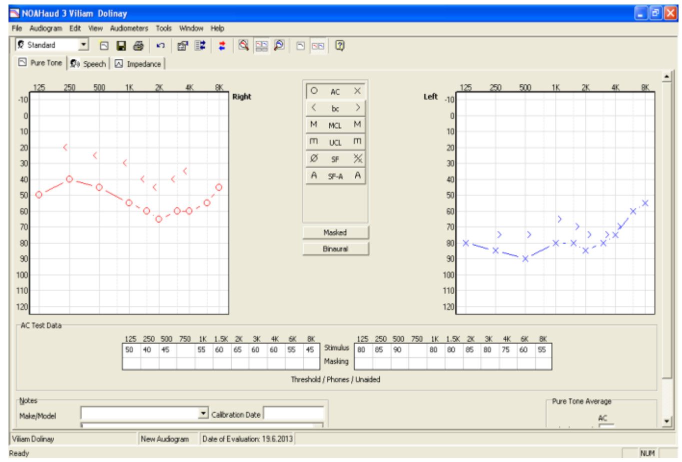

Fig. 11 Himsa NOAH audiometric module

B. Data evaluation

The main features implemented in modules for evaluating the audiometric result are described below:

- *Comparison of audiometric results*

The audiometric curves can be compared graphically and numerically, according to previous investigations. See figure 12. This function is based on the requirement of physicians who tested the system and consider it an important tool in the overall view of audiometric examination in individual patients during treatment.

- *Measurements with the comparison*

The module is based on the same principles as the results comparison. A measurement of the new records has on the background curve of the previous examination (if available). This feature is based on the requirement of paramedical staff that tested the system and considered it an important in carrying out repeated audiometric examinations.

- *Calculations and evaluation of results*

As mentioned in previous paragraphs, in the case of audiometric examination, the system automatically calculates the hearing loss according to Fowler and the average loss for a given frequency. These values, along with the information about the patient's age, which are implicit, allow us some additional criteria to calculate. Currently implemented are the following criteria:

- Classification of the hearing loss by age with regard to work in the risk of noise environments. See chapter IV.
- Classification of the hearing loss according to the decree of The Ministry of Labor and Social Affairs of Czech Republic.
- Determination of the grade of hearing impairment according to the WHO (World Health Organization)

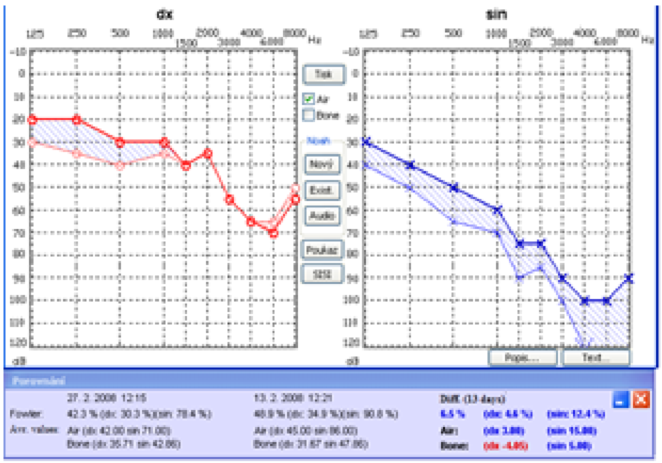

Fig. 12 Comparison of audiometric results in the proposed system

Grade of impairment	Corresponding audiometric ISO value	Performance
0 - No impairment	25 dB or better	No or very slight hearing problems. Able to hear whispers.
1 - Slight impairment	26-40 dB	Able to hear and repeat words spoken in normal voice at 1 meter.
2 - Moderate impairment	41-60 dB	Able to hear and repeat words spoken in raised voice at 1 meter.
3 - Severe impairment	61-80 dB	Able to hear some words when shouted into better ear.
4 - Profound impairment including deafness	81 dB or greater	Unable to hear and understand even a shouted voice.

Table 1 Grades of hearing impairment [6]

World Health Organization defines 5 grades of hearing impairments, see Tab. 1. Grades 2, 3 and 4 are classified as disabling hearing impairment. The audiometric ISO values are averages of values at 500, 1000, 2000, and 4000 Hz. System Fowler, which has all these information, in this case is responsible only for calculating averages value and select the appropriate grade and inform physician.

VII. Software Part of the Solution

The above described system modules were implemented in a Windows application called Fowler. The program was written in programming language C + + in Microsoft Visual Studio.

Fowler system also forms an important part in relation to the proposed expert system, however this feature will be described in one of the forthcoming works.

As a useful tool to streamline and make more pleasant work of doctors and nurses, Fowler system is already deployed in many ENT offices throughout the Czech Republic. And thanks to the practical and long-term deployment provides a means to further scientific use. The data obtained long-term use of Fowler, served as the basis for a set of training neural networks as a powerful engine for expert system support the diagnosis of diseases. Similarly, data collected and stored in the system database can be used for statistical analysis or creation of other expert systems based on artificial intelligence methods when large datasets are usually required. Figure below shows main window of application. The window contains fields for the data of the most frequently performed examination in ENT.

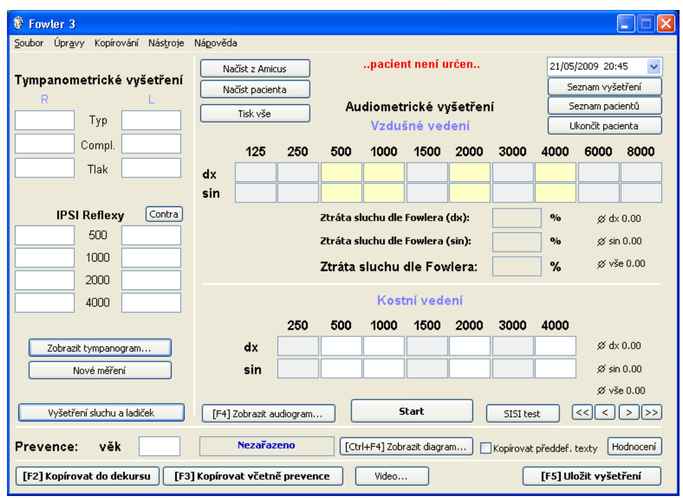

Fig. 13 Main application window

VIII. Conclusion

The system for measurement and subsequent evaluating the results of the tone audiometry and other ENT examinations was prepared. The system implements modules for communication with the hardware, data storage procedures and tools for visual and numerical representation of evaluation results. Important for the practical use are especially functions for data exchange with third-party software and modules for the comparison of audiometric examination during the evaluation, or during the examination. The calculation functions of the proposed system implements the evaluations according to World Health Organization and variety of criteria based on decree of competent authorities.

The system has been deployed for the practical tests in ENT specialist's offices. From the so far feedback it appears that the system became the useful tool for ENT physician; however, depending on their requirements, it will be certainly necessary to add additional functionality..

ACKNOWLEDGMENT

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